

EFFECTS OF MECHANICAL PUMPING ON THE ARTERIAL PULSE WAVE VELOCITY : PERIPHERAL ARTERY AND MICRO-VESSELS

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Abstract- We studied the effect of mechanical pumping on the response of peripheral arteries by focusing on the pulse wave velocity (PWV) in large arterial conduit and micro-vessels. The pressure waveforms were measured simultaneously at the brachial artery (BA), radial artery (RA) and finger. Impulse pumping was operated by alternatively adding 80mmHg pressure to the arm of normal subjects (N=10) in 3 second and relaxing to 0mmHg in 7 second for a period of 15 minutes. After pumping the segmental arterial PWV from BA to finger decreases due to the action of the change in endothelial relaxing factor. However, we find the decrease in PWV from BA to finger after pumping was contributed from the results of BA-RA, the PWV for the micro-vessels (BA-finger) on the contrary was increased.

Keywords- Mechanical Pumping, Pulse Wave Velocity, arterial response

I. INTRODUCTION

Pneumatic pumping has been shown to be effective in the therapy of both chronic and acute swelling due to trauma or surgery [1]. In literature, both mechanical or electronic circulation assist devices have been developed to compress or stimulates the muscle which induces the flow pulsation and the circulation locally [2-3]. Impulse pumping not only increased the venous return but also produced peak venous flow velocity significantly higher than that of the resting state. The hyperemic effects occurred within the venous system might be explained by the liberation of endothelial relaxing factor (ERF) of vascular smooth muscle that reacted to the pulsatile pressure changes [4]. However, it is not known how the arterial tree that composed of vessels of various sizes respond to the rhythmic compression.

The pulse wave velocity (PWV) that calculated based on the pulse transit time and the separation distance of recording sites has been widely used as an index of arterial distensibility, which offers a potentially useful clinical measure of arterial elastic behavior. We investigated the change of PWV in the upper extremity to study the effects of forearm impulse pumping on the arterial vessels. The immediate vascular response for the peripheral arterial conduit (brachial artery-radial artery; BA-RA) and the micro-vessels (RA-ring finger) to mechanical pumping was evaluated.

II. MATERIAL AND METHODS

Ten normal male subjects of age 24 ± 1 , heights 172 ± 5 cm were recruited in this study. All subjects were normotensive with no apparent cardiovascular diseases. Each gave informed consent to participate the experiments after receiving full explanation of the procedures involved. Volunteers were first asked to sit quietly for 5min, then the brachial systolic and diastolic pressures were measured. By positioning the tonometry pressure sensors at their BA and RA, an infrared sensor at their ring finger, the arterial pressure waveforms were recorded simultaneously. The arterial pressure waveforms collected from the three positions were digitized into a 586 personal computer via an A/D acquisition module.

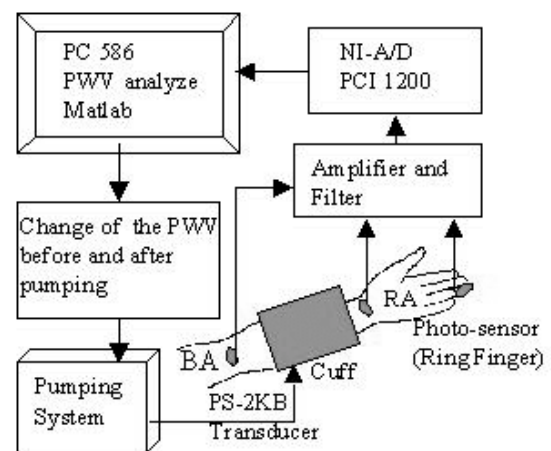


Fig. 1. Schematic of the mechanical pumping system for the forearm and the PWV calculations using the arterial waveforms at the brachial artery, the radial artery, and the ring finger.

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Fig. 1 shows the experimental setup schematically and the detail specifications are as following:

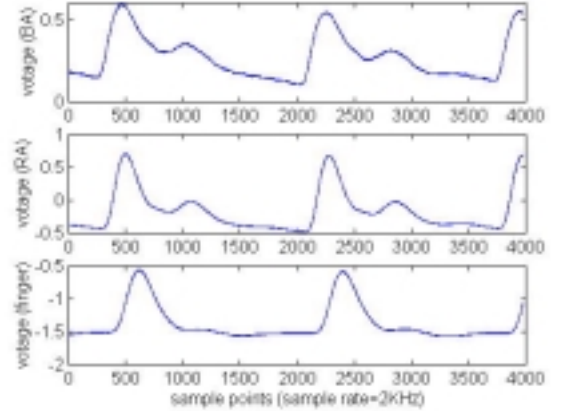
1. Pressure transducer: KYOWA PS-2KB strain-gauge type with output voltage 0.0807mV/V, 6mm diameter
2. Infrared photo-sensor with filter and amplifier, specifically designed for measuring the blood pressure wave at the ring finger [5]
3. Signal acquisition and process: PCI 1200 A/D-D/A from National Instrument, 12-bit resolution and the sampling rate was set at 2 kHz, and three seconds of data were taken typically.

The mechanical pumping was operated periodically by compressing the upper arm of subjects to 80mmHg pressure in 3 second and relaxing to 0mmHg in 7 second for a period of 15 minutes. We monitored the blood pressure waveforms at the BA, RA and ring finger every 3-5 minutes. The systolic and diastolic pressures were measured before and after mechanical pumping for comparison. Note that the changes in vascular properties due to temporary pumping are expected to return to their original status in a specific time. Therefore, once the compression action was stopped, the PWV were traced for 30 minutes to see the trend of recovery.

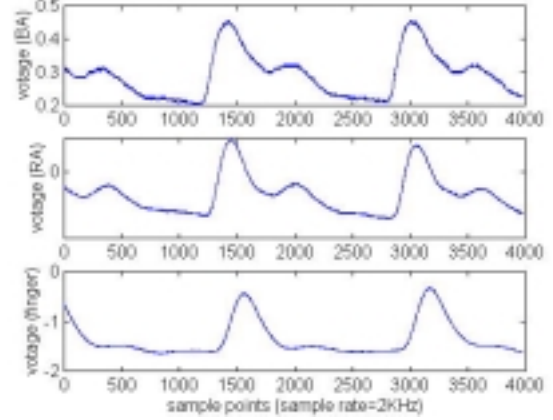
The segmental arterial PWV were determined from the foot-to-foot transit-time of pressure waveforms. PWV for arterial conduit is related to arterial stiffness and geometry as given by the Moens-Korteweg equation, $PWV = \sqrt{Eh / 2\rho R}$, where E is Young's modulus of the arterial wall; h the wall thickness; ρ the blood density; and R the arterial radius. The Bramwell-Hill equation, $PWV = \sqrt{\Delta P \cdot V / \Delta V \cdot \rho}$, further relates the PWV to the arterial compliance where ΔV and ΔP are the changes of blood volume and pressure respectively [6-7]. In this study the distance from the BA to RA were 24-28cm typically, and the distance from RA to ring finger were about 15-17cm. A computer software using MATLAB was written to perform the analysis.

III. RESULTS

Fig. 2 shows the typical results of pressure waveforms recorded simultaneously at the three positions (BA, RA and ring finger) before and after pumping. The pressure waveforms showed good repeatability for several cardiac cycles. The pulse pressures measured at the RA and the ring finger fall behind the BA pulse pressure. To look into the changes in peripheral resistance due to mechanical pumping, we compared the pressure waveforms that obtained before and 6 minutes after impulse pumping. Immediately after impulse pumping the heart rate was increased. However, no observable differences in pressure waveforms were observed.



(a) before pumping

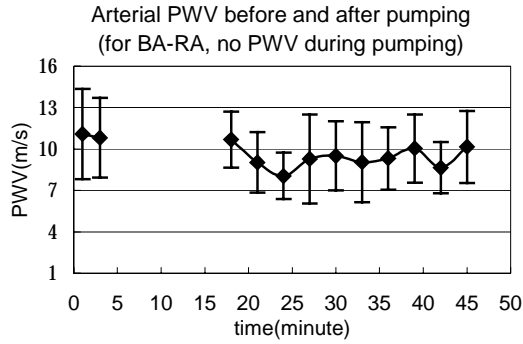


(b) 6 minutes after impulse pumping

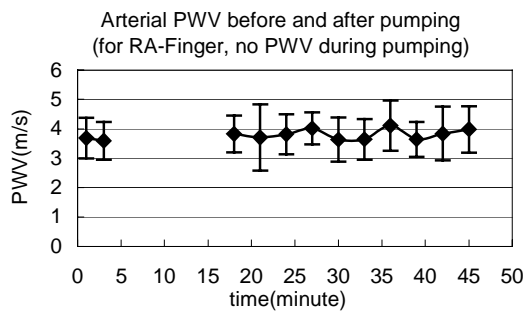
Fig. 2. Comparisons of blood pressure waveforms at BA, RA and ring finger (a) before pumping (b) 6 minutes after pumping.

The changes of arterial PWVs for BA-RA and RA-ring finger before and after mechanical pumping are shown in Figs. 3(a)(b). The PWV for large arterial conduit (BA-RA) for young subjects decreases after pumping. However, the PWV for smaller arteries (RA-ring finger) increased. The combined effects of PWV that based on the BA-ring finger decreased after pumping (Fig. 4). It was also observed that the heart rates fluctuating in the course of recovery after pumping (Fig. 5). The change in heart rate showed consistent trend as the changes in BA-finger PWV.

The variation in PWV data due to mechanical pumping were further expressed in the format of fractional change (%) as in Fig. 6. After impulse pumping the BA-RA decreased to about 15% comparing to the resting state, the RA-finger PWV increased by about 8%. Thus, the overall decrease in BA-finger PWV was only about 5%. The percentage changes of PWV between RA-finger seems to fluctuate with time in a relatively opposite manner as the response of artery between BA-RA and with a time lag.



(a)



(b)

Fig. 3. Changes of segmental arterial PWV after pumping in (a) large arterial conduit (BA-RA) (b) micro-vessels for young male subjects (N=10)

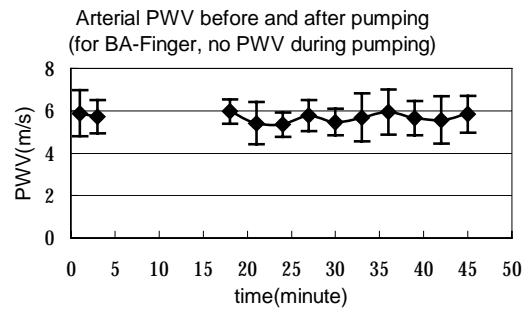


Fig. 4. Changes of segmental arterial PWV after pumping BA-ring finger for young male subjects (N=10)

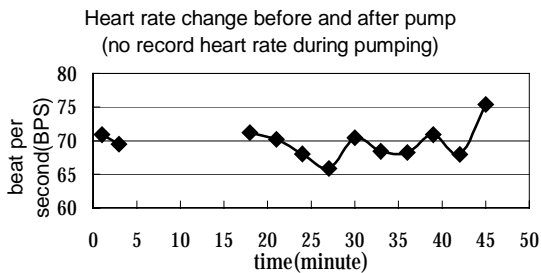
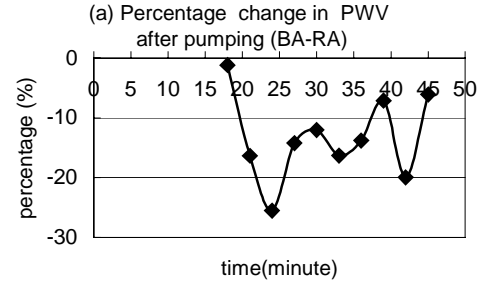
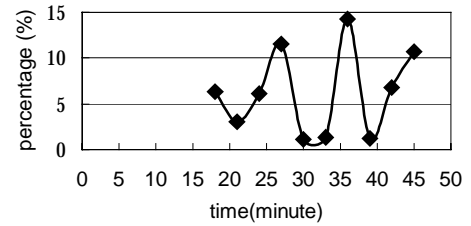


Fig. 5. Changes of heart rates before and after pumping for young male subjects (N=10)



(b) Percentage change in PWV after pumping (RA-Finger)



(c) Percentage change in PWV after pumping (BA-Finger)

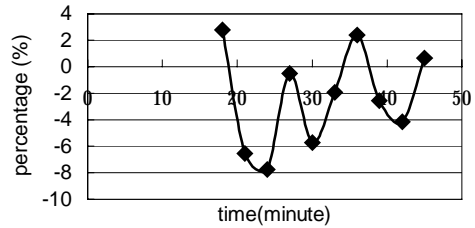


Fig. 6. Percentage changes in arterial PWVs after pumping in (a) large arterial conduit (BA-RA) (b) micro-vessels (RA-finger) (c) BA-finger for young male subjects (N=10)

IV. DISCUSSIONS

Mechanical pumping devices using inflatable cuffs which squeeze the calf and thigh have been shown to be effective for reducing the incidence of proximal deep-vein thrombosis and post-traumatic swelling [8-10]. In our previous study, we found the arterial compliance, arterial flow, and venous flow changed in the upper extremity after a short period of impulse pumping [11]. Due to sudden compression of the blood vessels, the blood was restrained to move and stored in the compartment, as soon as the constraint was removed the venous return at the brachial vein reached a peak velocity that was 2-3 times greater than the resting state. The venous flushing was thought to be the primary mechanism for removing thrombus. The arterial PWV from the BA to the ring finger reduced for both males and females after a 15 minutes pumping.

Since the changes in PWV may due to the alteration both in arterial geometry (diameter and thickness) and/or stiffness (E), we attributed the change in PWV to arterial

vessel relaxing after periodic compression [12]. The RA blood flow has been seen to increase after mechanical pumping [11] while the arterial stiffness decreases.

Since the PWV for micro-vessels was never paid much attention in the literature, we tried to distinguish the change of arterial PWV to vessels of different levels. Although the diameter of BA increases slightly after pumping, the blood flow into the hand also increases. However, the small arteries (RA-finger) seem to be stimulated to counteract the reactive hyperemia of large arterial conduit (BA-RA) after pumping. The increase in arterial PWV in RA-finger may be caused by the local vaso-constrictor in the arteriolar level.

V. CONCLUSION

A mechanical air pumping system has been developed to compress the arm of normal subjects and estimate the outcome of vascular responses by observing the arterial PWVs. We calculate the PWV based on the foot-to-foot phase delay of the pressure waveforms taken at the brachial artery, radial artery and the ring finger. The arterial PWV in the upper extremity decreased after repeatedly pressurizing the arm in 3 second and relaxing in 7 second alternatively for a period of 15 minutes. The vessel relaxing during pulsatile loading is believed to be the major cause of decrease in PWV of large arterial conduit. However, the PWV in the micro-vessels showed counteracting effects.

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